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FEASIBILITY STUDY - HYDRODESULFURIZATION OF FUELS UNDER CORONA DISCHARGE CATALYSIS

BY

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Final Report

Feasibility Study - Hydrodesulfurization of Fuels Under Corona Discharge Catalysis

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Abstract

A corona discharge hydrodesulfurization process was investigated for fuel oil containing 2.57% sulfur. A concentric tube, packed-bed reactor was used for the study. Up to 23% reduction in sulfur content, a linear relationship was shown between energy input to the oil and decrease in sulfur concentration. The energy required was too high to justify practical application of the process at its present state of development.

Use of a desulfurization catalyst as a dielectric packing in the corona reactor improved the efficiency sixfold but reintroduced the problem of spent catalyst regeneration.

In a separate short study, powdered bituminous coal was exposed to hydrogen in a corona discharge in the hope of converting FeS_2 to magnetic FeS. Treated samples are being analyzed by the U. S. Bureau of Mines.

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PART 2: CORONA HYDRODESULFURIZATION OF FUEL OIL

Introduction

When an electric field is applied to the series combination of a gaseous gap and a dielectric solid, the gas will break down and conduct at an applied voltage much lower than that required to break down the solid. The dielectric barrier acts as a series ballast to stabilize the discharge, which appears as a soft glow. This form of discharge at atmospheric pressure is defined as a corona discharge. Using this form of electrical energy, chemical reactions which proceed only with difficulty by conventional means may take place with reasonable efficiency. The chemical reactions caused by electrical discharge are essentially those involving active species, such as excited molecules, free radicals, and ions, formed by inelastic collisions between accelerated electrons and molecules.

Utilization of a hydrogen plasma produced by a corona discharge for hydrocracking of coal, coal tar, and related hydrocarbons was studied in this laboratory during the past two years. Corona discharge chemical reaction techniques for gaseous, gas-liquid, and gas-solid systems were developed. Although the energy requirements were high, the major products, as predicted, were various smaller hydrocarbon fragments and polymerized compounds formed by combination of free radicals.

Desulfurization of fuel oils is of growing importance from the standpoint of air pollution. Catalytic hydrodesulfurization of crude oil or residual oils has been successfully tested on both pilot plant and commercial scales. The HDS process and H-Oil process seem to be promising candidates (1). From the laboratory's extensive experience in the corona hydrocracking of hydrocarbons, it appeared that a possibility existed for applica-

tion of a corona process for desulfurization of the fuel oil. For simple organic compounds the dissociation energy of a C-S bond appears to be smaller than that of C-C or C-H bonds. High energy electrons or hydrogen atoms produced in a corona discharge may react with the fuel oil, removing sulfur as hydrogen sulfide without altering physical properties of the oil greatly. Reactions between gaseous active species and the oil were expected to take place primarily at the gas-oil interface.

Experimental Materials and Apparatus

No. 6 residual fuel oil (Venezuela crude), which was supplied by the Turbine Department of the Company, was used for the studies. This oil contained 2.57% of total sulfur. The reactant gases were obtained from the Matheson Company.

A flow sheet of the apparatus is given in Figure 1 and a photograph of the assembled apparatus is shown in Figure 2. The oil was fed into the reactor dropwise from the graduated feed bottle. The reacting gases were fed concurrently at a definite flow rate determined by the flowmeters.

The corona reactor was fabricated from quartz and was of a concentric tube design similar to an ozonizer cell. The inside of the inner barrier (40 mm O.D. and 38 mm I.D.) was coated with tin oxide and the outside of the outside barrier (48 mm O.D. and 46 mm I.D.) was tightly covered with a 10 mesh steel screen. The former was connected to the high voltage terminal; the latter to ground. An outside jacket was provided to cool the reactor by forced air flow. A thermometer with a metal cover was placed in the center of the inner electrode tube at a point equidistant from the ends of the discharge zone. This thermometer was used to indicate the reactor temperature and also to provide a path for high voltage current. The annular discharge space (46 mm O.D., 40 mm I.D., 200 mm high)

was packed with 10 x 20 Tyler mesh aluminum oxide grains. This granular packing provided a large interface between the oil and gas, in addition to assisting the attainment of a uniform corona discharge. In several experimental runs catalyst pellets were used as packing in place of aluminum oxide grains.

The corona generating equipment used in these experiments consists of a high voltage, high frequency power supply, with associated instrumentation to control and measure the corona power generated. The basic power and instrumentation circuit is shown in Figure 3. The output of a 10,000 cycle, 30 KW, inductor-alternator is fed to the primary of a 50 KV high voltage transformer and, in turn, to a tuned circuit, to a corona cell, and to the high voltage instrumentation. Inductor-alternator output voltage and subsequently, transformer high voltage, are controlled from zero to maximum output by varying the alternator field current.

Since the corona cell itself represents a capacitive load on the inductor-alternator and the transformer, a tuning circuit is provided for power factor correction, so that the high voltage transformer sees only the resistive load represented by the corona power dissipated in the corona cell. This tuning circuit consists of an air-core, foil wound choke and a vacuum-capacitor bank, connected as a parallel resonant circuit across the transformer secondary.

High voltage instrumentation includes a vacuum tube voltmeter operating from a capacitance voltage divider, for reading the peak voltage applied to the corona cell, and a bridge circuit for determining corona power by means of the parallelogram-oscilloscope technique. This technique shows the relationship between the voltage on the cell electrodes at any instant and the charge flow in the circuit up to that instant. Using the area of parallelogram on the oscilloscope, the power input to the reactor was computed.

Experimental Procedures

While passing the reacting gas, a corona discharge was applied to the reactor. Heat developed by the discharge raised the reactor temperature. When the desired reactor temperature was obtained, the experimental runs were started by feeding the oil into the discharge space of the reactor. At the end of the run the oil which had accumulated in the bottom receiver was analyzed for sulfur content. The determination of total sulfur was done by the A.S.T.M. method (2).

Experimental Runs

A total of twelve experimental runs were made. The process variables investigated were: (1) gas flow rate, (2) type of reactant gas, (3) corona energy input per unit weight of the oil, (4) reactor temperature, and (5) use of catalyst. The process conditions employed are described below for each experimental run. They are also summarized in Table 1.

Run #1: The oil was fed into the reactor at a rate of 96 g/hr. using 180 watts of corona power. The flow rate of hydrogen was 9 l/hr. and the reactor temperature averaged 240°C. The energy input was calculated to be 0.71 KWH/LB. oil. Analysis of the effluent oil revealed no reduction of sulfur content.

Run #2: Except for a higher oil feed rate, 192 g/hr., the conditions for Run #1 were duplicated. The reactor temperature averaged 240°C and the energy input was calculated to be 0.36 KWH/LB. oil. Again, no reduction of the sulfur content was observed.

Run #3: Analysis of Runs #1 and #2 indicated that the flow rate of hydrogen may have been too low to provide adequate contact between the oil and gas. Therefore, the hydrogen flow rate was

raised to 30 l/hr. and the oil feed rate was cut down to 25 g/hr. The corona power input was 140 watts and the reactor temperature was averaged 270°C. The energy input was calculated to be 2.5 KWH/LB. oil. The analysis showed a reduction in sulfur from 2.57 to 2.29%.

Run #4: In this experiment it was planned to raise the reactor temperature while keeping the corona energy input per pound of oil at a level approximately equal to that used for Run #3. The power input was increased to 194 watts and the oil feed rate set at 44 g/hr. The reactor temperature averaged 315°C. The energy input was calculated to be 2.0 KWH/LB. oil. The sulfur concentration in the effluent oil was 2.35%, a reduction of 0.22%.

Run #5: The reactor used for Runs #1 - #4 had only one opening for feed at the end. By qualitative observation during the previous four runs, somewhat uneven distribution of the oil in the packed bed was suspected. Thus, the reactor was modified by equipping it with a feed nozzle having two openings located 180° apart on the circumference. For the rest of the investigations, this modified reactor was employed. In Run #5 an oil feed of 340 g./hr.; H_2 flow rate, 60 l/hr.; and power input, 177 watts were chosen. The reactor temperature was averaged 230°C. The energy input to the feed oil was calculated to be 0.27 KWH/LB. oil. Even distribution of the oil in the packed bed was achieved in this reactor; however, the sulfur concentration in the effluent oil was 2.31% and the desulfurization efficiency was disappointingly low.

Runs #6: The poor desulfurization efficiency observed in the previous five experiments using H_2 may have been due to the low concentration of hydrogen atom available for the reaction. Thus, it was decided to change the reactant gas to ammonia. It is known that ammonia is dissociated into $NH_2 + H$ by an electron energy of about

5 e.v. This is considerably lower than the 8.6 e.v. for dissociation of hydrogen. The breakdown field strength of ammonia at one atmosphere is, 52 KV/cm, much higher than the value for hydrogen (13 KV/cm). Because of this higher electric field and lower dissociation energy level, an improvement of the desulfurization efficiency might be achieved. In Run #6 an oil feed rate of 30 g/hr.; ammonia feed, 54 l/hr.; and corona power input, 175 watts were used in Run #6. The calculated energy input was 2.2 KWH/LB. oil. The reactor temperature averaged 300°C and the sulfur concentration in the effluent was 2.35%. The effluent gas contained about 4% H_2.

Run #7: The energy input to the oil was lowered to 0.21 KWH/LB. in this experiment. The oil feed rate was 310 g/hr., the flow rate of ammonia, 54 l/hr., and the power input, 140 watts. The reactor temperature averaged 230°C. No reduction of sulfur in the effluent oil was observed.

Run #8: The use of an ammonia-hydrogen mixture was tested using conditions similar to Run #7. A mixture having H_2/NH_3 = 1.4 (mol. ratio) was fed at a flow rate of 58 l/hr. The oil feed rate was 250 g/hr. and the corona power input, 180 watts. The reactor temperature averaged 240°C. The energy input was calculated to be 0.32 KWH/LB. oil. The sulfur content of the oil was reduced to 2.45%, a result better than that found for hydrogen or ammonia alone.

Run #9: The experimental results described above showed low efficiencies for desulfurization of the oil. Thus, the use of hydrogenation catalyst in corona discharge was tested. The catalyst employed was cobalt and copper in oxide form supported on aluminum oxide (supplied from the Harshow Chemical Co.). This catalyst in pellet form was used as packing in the discharge space. Although some irregularities in feed rate was seen in this run, it was estimated to be about 71 g./hr. The hydrogen feed was 60 l/hr.

and the power input, 100 watts. The reactor temperature was 290°C. The calculated corona energy input was 0.64 KWH/LB. oil. The sulfur content in the effluent oil was 2.00%, indicating considerable increase in desulfurization efficiency.

Run #10: This run was essentially a repetition of Run #9. The oil feed was 80 g/hr., the hydrogen flow rate 60 l/hr., and the power input 100 watts. The reactor temperature was 280°C. The calculated corona energy input was 0.76 KWH/LB. oil. The sulfur concentration in the effluent oil was 2.08%. Again, considerable increase in desulfurization efficiency was achieved by employing the catalyst.

Run #11: In this run, the corona energy input to the oil was lowered using the same catalyst system. Employing an oil feed rate of 285 g./hr., and a power input of 110 watts, the energy input of the oil was reduced to 0.13 KWH/LB. The reactor temperature was 260°C. The sulfur content in the oil was reduced to 2.44%.

Run #12: In this run, the reactor temperature was increased by raising the power input to 150 watts, keeping other conditions similar to Run #9 and #10. An oil flow rate, 68 g./hr., hydrogen feed, 60 l/hr., and the reactor temperature, 340°C, were chosen. The energy input was calculated to be 1.0 KWH/LB. oil. The results showed 2.50% sulfur in the effluent oil. The sulfur concentration seems to be high comparing the results obtained in Run #9 and #10. This poor performance was probably due to the deterioration of the catalyst activity caused by successive use of the catalyst. This hypothesis seems valid since no hydrogen sulfide was observed in the effluent gas in Run #9 and #10, indicating that it had been absorbed on the catalyst. Thus, the result of this experiment may be better classified into the aluminum oxide grain packed bed reactor system.

Summary of the Experimental Results

Effect of Flow Distribution

The reactor first employed had an oil feed nozzle which had only one opening at the end. Qualitative observation during the initial runs indicated that distribution of the oil in the annular packed space was not uniform, resulting in a less efficient utilization of the reaction space. Therefore, the feed nozzle was modified in order to permit more efficient utilization of the discharge space. However, there was no significant effect on the desulfurization efficiency.

Effect of Temperature

The reaction temperature was varied from 230 to 350°. In this temperature range no significant effect of reaction temperature on the sulfur removal was observed.

Effect of Corona Energy Input

Corona energy input was varied from 0.2 to 2.5 KWH/LB. oil. As the corona energy increased, the sulfur concentration in the effluent oil decreased.

Effect of Catalyst

Aluminum oxide grains in the discharge space were replaced by catalyst pellets. The catalyst was cobalt and copper in oxide form supported on porous aluminum oxide. The results indicated a considerable increase in sulfur removal efficiency. When using this cobalt catalyst there was no hydrogen sulfide in the effluent gases, suggesting that the hydrogen sulfide produced may be absorbed on the catalyst.

Effect of Reactant Gases

Hydrogen, ammonia and a mixture of ammonia and hydrogen were tested. For the ammonia, the results were similar to those for hydrogen. About 4% of H_2 was observed in the effluent gas by mass spectroscopy. A mixture of NH_3 and H_2 gave a better efficiency for sulfur removal. This may be due to the higher hydrogen atom concentration produced in the higher electric field required to sustain the discharge in this gas mixture as compared to that for H_2 alone. Further investigations are necessary to clarify the true cause.

Discussion

In Figure 4 the decrease in sulfur concentration, $\Delta S(\%)$, was plotted against the corona energy input, W (KWH/LB. oil). All the data were pooled in this figure and a linear relationship was found.

$$\Delta S = kW \qquad (1)$$

The values for k were 0.11 and 0.70 %/KWH/LB. oil for H_2 with and without catalyst respectively. Extrapolating equation (1), 80% sulfur removal from this oil (2.06% concentration decrease) would require corona energy inputs of 18.7 and 2.9 KWH/LB. oil for H_2 with and without catalyst, respectively, There is some question of the validity in estimation by extrapolation for the reasons described below. In any event, these values seem to be rather high to justify the practical application of this process.

The nature of the sulfur compounds which exist in petroleum and its various fractions have been summarized by McCoy and Weiss (3). They discuss in some detail the hydrodesulfurization process with particular reference to reaction kinetics, thermodynamics, and the performance characteristics of various catalysts. The authors

separate petroleum sulfur compounds into two classes; thiophenic and non-thiophenic. Non-thiophenic compounds include elemental sulfur, aliphatic and alicyclic sulfur compounds such as alkane thiols, alkane sulfides, cyclic sulfides, and alkane disulfide, and aromatic mercaptan precursors such as phenyldecylsulfides. Thiophenic compounds include simple and complex thiophens as well as compounds such as diphenylsulfides in which the sulfur is linked to two aromatic rings. The distribution of sulfur compounds in straight run residue oils and asphalt is shown in Table 2.

Several processes for the catalytic hydrodesulfurization of the residual oil had been tested in a commercial or pilot plant scale, converting various sulfur compounds to hydrogen sulfide and saturated and/or aromatic hydrocarbons (4). The major reactions appear to involve simple carbon-sulfur bond rupture and saturation of the free valencies and of olefinic double bonds. In general, aromatic rings are not saturated, but partial ring saturation may precede carbon-sulfur bond rupture in the case of dibenzothiophene.

As shown in Table 2, the sulfur content of the straight run residue oil was about 50% non-thiophenic and 50% thiophenic. In asphalt only about 10% was non-thiophenic. The distribution of the sulfur compounds in the No. 6 residual fuel oil used in this study may lie between the values for these two fractions reported. Hydrogen atom produced in the corona discharge may be able to rupture the carbon-sulfur bond of the sulfur compounds described above. However, the case of dissociation of the sulfur compounds obviously depends on their molecular structure, with thiophenic sulfur compounds having a higher resistance to dissociation than non-thiophenic sulfur compounds. Thus, there is an uncertainty in extrapolation of equation (1) to estimate the power requirement for higher percent reduction of sulfur compounds.

In a previous study on corona hydrocracking of various hydrocarbons, the energy yield was determined (5). Typical energy yields for hydrocracking were 10.9, 0.7, 1.5, 3.9, and 0.93 g/KWH for m-cresol, α-methylnaphthalene, tetrahydronaphthalene, decahydronaphthalene, and 9,10-dihydrophenanthrene, respectively. The use of nickel or cobalt hydrogenation catalyst increased the yield considerably. For aliphatic hydrocarbons typical energy yields for cracking (no hydrogen was used) were 19.7, 23.0, 11.7, 10.3 and 4.6 g./KWH for n-butane, n-butene, propane, ethane, ethylene, and methane, respectively. Among hydrocarbons tested, it was found that the ease of cracking follows roughly in an order of aliphatic, hydro-aromatic, and aromatic structure. The energy yield of desulfurization calculated from equation (1) was 0.5 g. sulfur per KWH without catalyst and 3.2 g. sulfur per KWH with catalyst. Since the exact parent molecular structure is unknown, it is difficult to make a more exact comparison of the energy yield between the hydrocarbons and the sulfur compounds.

The previous experiments on hydrocarbons were made in the vapor phase, but the desulfurization experiment was made in a gas-liquid two phase system. In this system reactions probably take place at the interface, and the diffusion of hydrogen atom through the boundary film becomes important. In the atmospheric corona discharge system, the average electron energy is around 2 electron volts. The concentration of active hydrogen atom in the gaseous phase itself seems to be fairly low. Thus, the diffusion of hydrogen atom should be slow. Comparing the vapor phase reaction system, the diffusion of hydrogen atom through the boundary film is actually an additional resistance to chemical reaction paths. Thus in the gas-liquid system there should be a higher tendency for the recombination of hydrogen atom, resulting in a less accessibility of hydrogen atom to the reaction at the interface.

Conclusions

The corona discharge hydrodesulfurization process was investigated for No. 6 fuel oil having 2.57% sulfur. A concentric electrode packed bed reactor was used for the study. In a range of sulfur concentration decrease up to 0.6%, linear relationships were found between energy input to the oil and sulfur concentration decrease. The energy requirement for desulfurization seems to be high to justify the practical application of the process. The use of catalyst improved the efficiency sixfold, but the regeneration of the catalyst may be costly.

PART II: CORONA INITIATED REDUCTION OF FeS_2 IN COAL

Introduction

1. Prospects for Hydrodesulfurization of Coal

The principle of corona hydrodesulfurization of fuel oil was thought originally to be applicable also to coal. However, from the reasons described below some doubt arose.

It is generally agreed that coal has a porous structure consisting of macro and micro pores. The macropores may be considered to be alleys connecting to the network of micropores accessible to internal molecular structure of coal. The sulfur compounds in coal are conveniently classified into three groups; pyritic, organic, and sulfate. The former two are the principal constituents of most coal.

Pyritic sulfur is primarily FeS_2 and is either well distributed in coal structure or in discrete particles. On the other hand, organic sulfur is the sulfur contained in the complex coal molecular configurations and well distributed in the coal structure. In order to have reactions between the organic sulfur and hydrogen atom, transportation of hydrogen atom through the macropores to the reaction site in the interior of coal structures is necessary. However, in the macropores, where the flow of the gas is probably governed by Poiseuille's law, hydrogen atoms will recombine to hydrogen molecules fairly rapidly. Thus, the concentration of atomic hydrogen should be small at the reaction sites in the interior. Even if hydrogen atoms exist in the reaction site, the decomposition of the organic sulfur probably requires much higher energy than that required for decomposition of sulfur compounds in the oil, because of more complex, condensed aromatic molecular structure of coal. Theoretically, there is a possibility of having electric discharge in the pore structure preferentially

by the void discharge mechanism. However, the release of water vapor of hydrocarbon vapors from the coal structure may hinder this reaction. Therefore, the prospects for decomposing organic sulfur by corona techniques are not bright. However, the decomposition of the pyritic sulfur by corona hydrogen plasma may be more probable than organic sulfur, especially if pyrite exists in a fashion discrete from the coal structure.

2. Conversion of FeS_2

We were informed that a process for the magnetic separation of pyrite sulfurs was being studied by the U. S. Bureau of Mines (3). Since FeS is magnetic, the separation of pyrite from coal is possible, if FeS_2 is reduced to FeS. For this separation method the reduction of FeS_2 to FeS only at the particle surfaces may be sufficient. At temperatures higher than 350°C., FeS_2 decomposes to FeS thermally, but this temperature is too high to keep the physical properties of coal unchanged. By using the hydrogen corona plasma this reduction to FeS_2 may be possible at temperatures low enough to prevent appreciable changes in the physical properties of the coal. Thus, the investigation was directed toward the possibility of using a corona hydrogenation process for reduction of pyritic sulfur which, if successful, could lead to an application in coal preparation processes by combination with magnetic separation methods.

Experimental Materials and Apparatus

A sample of -48 mesh Pittsburgh seam, high volatile A bituminous coal from the Ireland mine, which was sent from the Bureau of Mines, was used for the study. Analytical data for this coal on a moisture free basis are:

> volatile matter 39.5%, fixed carbon 45.4%, ash 15.2%, hydrogen 4.8%, carbon 68.8%, nitrogen 1.7%, oxygen 5.1%, total sulfur 4.4%, pyritic sulfur 2.45%, organic sulfur 1.84%, and sulfate sulfur 0.03% (7).

A concentric electrode quartz reactor similar to the one described in Part I was employed for the study. The annular discharge space (46 mm O.D., 40 mm I.D., and 200 mm high) was packed with the coal. The bottom part of the reactor was packed with aluminum oxide grains to support the coal samples. The top part of the reactor was also packed with the grains to prevent the discharge in the space above the coal bed. This reactor had no outer jacket and the reactor temperatures were determined by a thermistor attached to the outside of the reactor wall and a thermometer placed in the center of the inside electrode. Both of them are located at the middle height of the reactor. The corona power supply system has been described in Part I.

Experimental Procedures

Hydrogen was admitted to the bottom of the packed reactor at a flow rate of 60 l/hr. The corona power was applied and the variation in reactor temperature was recorded. After the specified time, the power was shut down, the sample was taken out and the weight loss of the coal determined. In one experiment the volatiles derived from the coal were condensed in a cold trap. The reacted samples were sent to the Bureau of Mines to determine the magnetic characteristics.

Experimental Runs

Run 1: The coal sample, 72 g. was placed in the reactor and 120 watts of corona power was applied for 60 minutes. The reactor temperature stabilized at 265-285°C. after a 20 minute heat-up period. The weight loss of the coal was 3 g.

Run 2: An 80 g. coal sample was used and 120 watts of the corona power supplied. After 20 minutes, the reactor temperature reached 250°C. but the reactor failed by arcs produced locally. The weight loss could not be determined. In a cold trap 150 cc. of gaseous

product was obtained. The composition of this gas was 5% H_2S, .5% of thiophene, .5% of COS, and the balance of C_2-C_3 hydrocarbons. This run may be of value in studying the reaction during the unsteady initial heating-up period, but the local development of high temperature by arc formation should be taken into consideration in any conclusions reached.

Run #3: A 90 g. coal sample was used and 100 watts of the corona power applied for 120 minutes. After 20 minutes of initial heating-up period, the reactor temperature was stabilized at 240-260°C. The weight loss of the coal was 5 g.

Discussion

The treated samples were friable and easily handled. They were mailed to the Bureau of Mines for determination of their magnetic characteristics.

The presence of hydrogen sulfide in the off gas from Run #2 indicates hydrogen atom attack on some sulfur compounds in the coal but a final decision on the question of FeS_2 reduction must await magnetic separation test results.

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Table 1

Corona Beneficiation of Fuel Oil - Experimental Conditions and Results

Experiment No.	Oil Feed Rate c/hr.	Gas and Feed Rate l/hr.		Corona Power Watt	Reactor Temp. °C	Reactor Packing	Corona Energy KWH/lb. oil	Sulfur Content of Effluent Oil (%)	Reduction of Sulfur, ΔS (%)
1	96	H_2	9	150	240	Al_2O_3	0.71	2.55	----
2	192	H_2	9	150	240	Al_2O_3	0.36	2.58	----
3	25	H_2	60	140	270	Al_2O_3	2.5	2.29	0.28
4	44	H_2	60	194	315	Al_2O_3	2.0	2.35	0.22
5	300	H_2	60	177	230	Al_2O_3	0.27	2.51	0.06
6	36	NH_3	54	175	300	Al_2O_3	2.2	2.35	0.22
7	310	NH_3	54	140	230	Al_2O_3	0.21	2.63	----
8	250	NH_3	58	180	240	Al_2O_3	0.32	2.45	0.12
9	71	H_2	60	100	290	Co catalyst	0.64	2.00	0.57
10	60	H_2	60	100	280	Co catalyst	0.76	2.08	0.49
11	285	H_2	60	110	260	Co catalyst	0.18	2.44	0.13
12	68	H_2	60	150	340	Co catalyst	1.0	2.50	0.07

Table 2

Sulfur Compounds in Residual Oil and Asphalt

Source	Sulfide	Non-Thiophenic	Thiophenic	Total
Straight run-short residue	1.0	1.0	1.08	2.08
Straight run-long residue	0.88	0.89	0.81	1.70
Asphalt	----	0.16	1.42	1.58

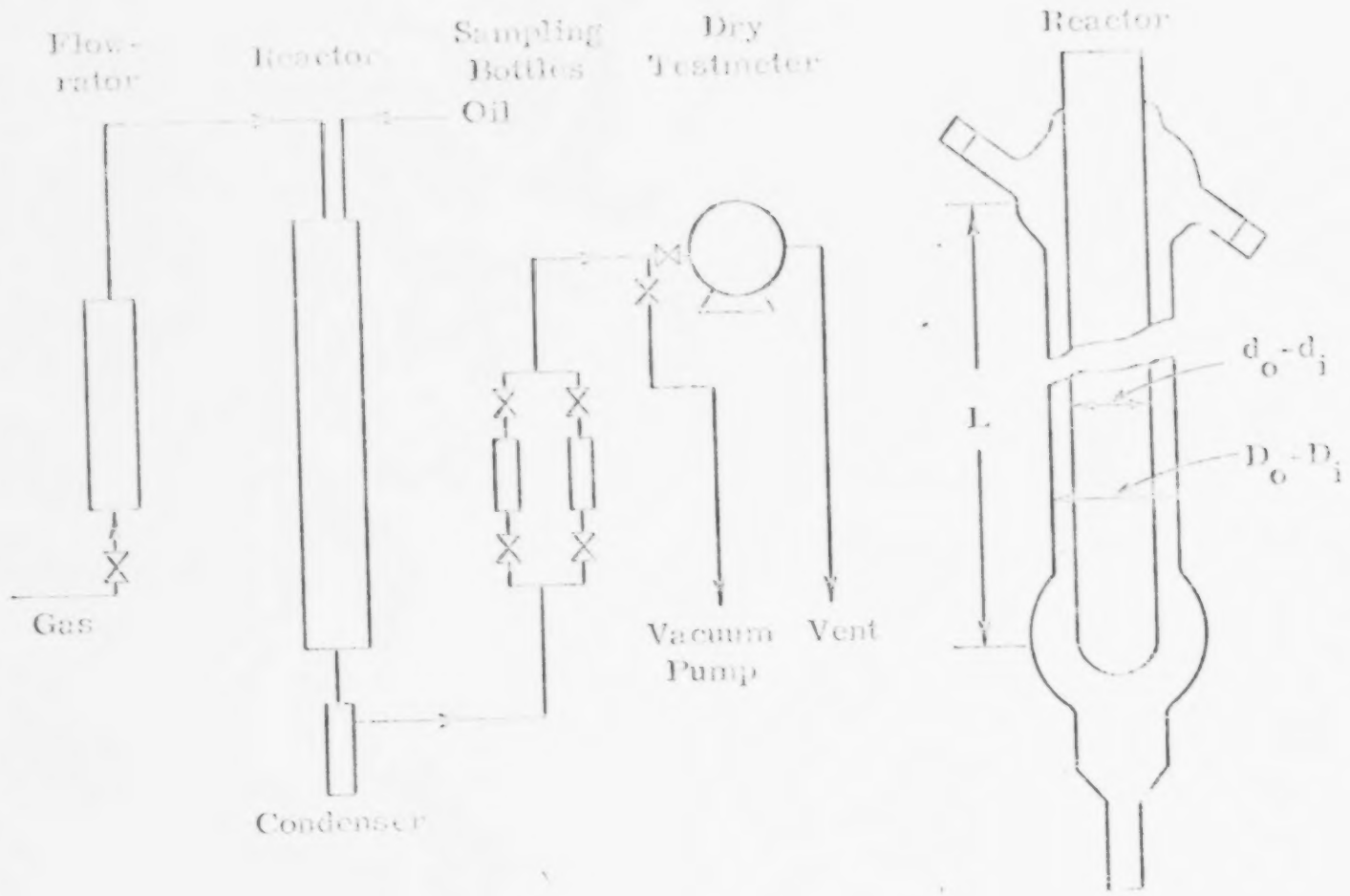
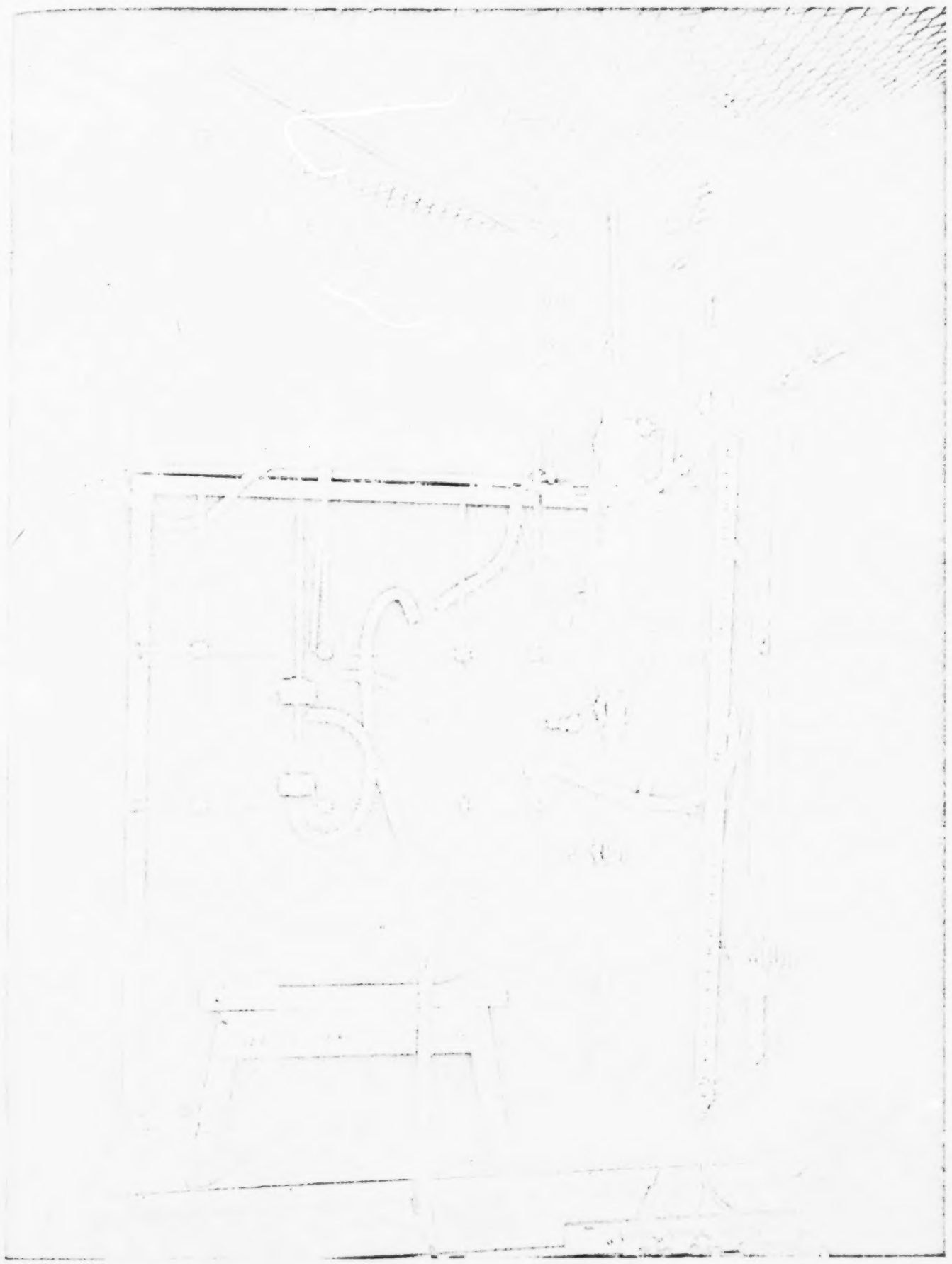


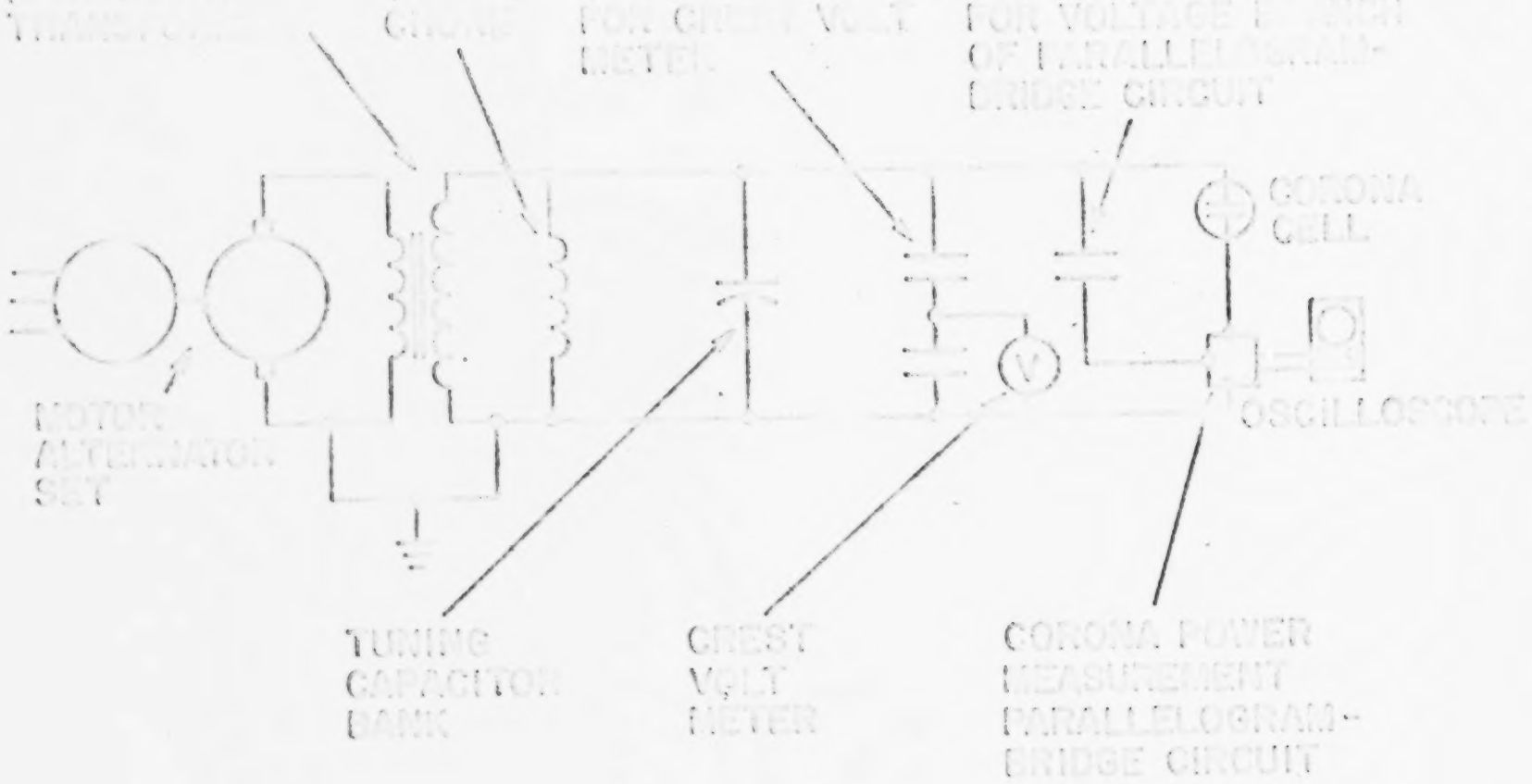
Figure 1 Flow Diagram of the Apparatus and the Reactor.



NOT REPRODUCIBLE

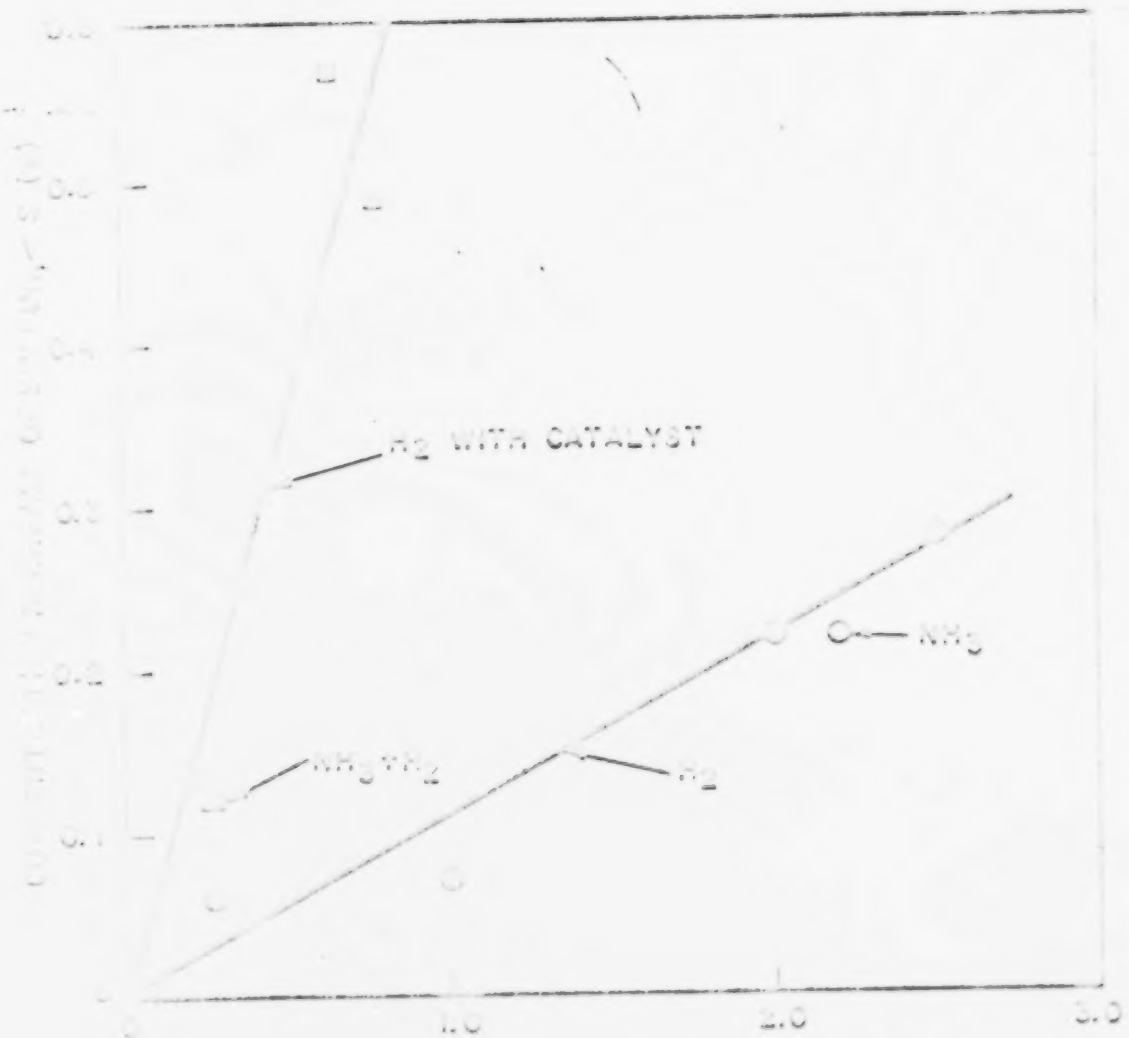
FIGURE 2

Reaction Train (ATL Photo844201)



BASIC POWER AND INSTRUMENTATION CIRCUIT

FIGURE 3



DESULFURIZATION OF THE FUEL OIL BY CORONA DISCHARGE

FIGURE 4